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EFFECT OF CIGARETTE SMOKING ON RESIDENTIAL NO_2 LEVELS

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Two studies evaluating the levels and sources of nitrogen dioxide in approximately 90 employee homes in the Richmond area with continuous sampling during the weeks of August 5, 1980, and February 9, 1981, were performed using samplers in the living room, bedroom, kitchen, and outdoors. Additional data were collected concerning appliance usage, heating/cooling plant, ventilation and cigarette smoking. Results were analyzed using BMDP routines. The largest contributor to NO_2 concentration was found to be gas-fired kitchen appliances. The mean kitchen level for homes with gas appliances during the winter study was ~188 $\mu g/m^3$. Excluding participants with gas kitchens, incremental influence due to cigarette smoking was detected. The 7-day, 3-room average level of NO_2 in the homes of nonsmokers and smokers without gas-fired appliances was 12 and 15 $\mu g/m^3$, respectively, in the summer. The corresponding winter values were 19 and 22 $\mu g/m^3$. Furthermore, the individual levels of NO_2 in the homes of smokers were generally below both the adjacent outdoor level and the National Ambient Air Quality Standard limit for annual exposure.

Introduction

With Americans spending more than 90% of their time indoors, and with the move toward greater energy savings and thereby tighter residences and workplaces, there has been an increased emphasis on monitoring the levels of indoor air contaminants and correlating the levels with a variety of sources (Budiansky, 1980).

Nitrogen dioxide is corrosive, reactive and highly oxidizing, and may be toxic at high concentrations (Hueter *et al.*, 1973). Its half-life indoors is less than ⅓ that of CO (Wade *et al.*, 1975). Experiments at Philip Morris and elsewhere show that NO_2 results from oxidation of nitric oxide in aging cigarette smoke (Norman and Keith, 1965; Barkemeyer and Seehofer, 1968; Sloane and Kiefer, 1969; Vilcins and Lephardt, 1965).

In almost all published studies, a strong correlation has been shown between NO_2 levels and the presence and operation of gas cooking appliances (Spengler *et al.*, 1979; Hollowell, Budnitz and Traynor, 1977; Hollowell *et al.*, 1979; Eaton *et al.*, 1973). Although it is thought that cigarette smoking contributes to the NO_2 level, few researchers have demonstrated that relationship (Kasuga *et al.*, 1979; Weber and Fischer, 1980; Meyer *et al.*, 1981; Goldstein *et al.*, 1979).

Weber and Fischer (1980) investigated air pollution due to tobacco smoke in 44 workrooms. The contribution to the level of NO_2 from smoking was claimed to be 45 $\mu g/m^3$; more precisely, the measurement was the difference in NO_2 level between the unoccupied rooms at 4 to 6 a.m. and the occupied rooms. Since no room was totally free of smoke, it is difficult to assess the smoking contribution to the NO_2 level. The difference in levels of nicotine between unoccupied and occupied rooms was also measured; the results suggest only a +0.36 correlation with the corresponding NO_2 value, which questions how much of the 45 $\mu g/m^3$ is actually due to tobacco smoking. Weber and Fischer did not take into account the diurnal patterns of NO_2 (Hueter *et al.*, 1973). NO_2 is at minimum concentrations during nondaylight hours. As human activity, especially automobile traffic, increases in the hours just after dawn, the concentration of the primary contaminant, NO, increases. Then, as the ultraviolet energy from the sun becomes available, the NO_2 concentration increases (Hueter *et al.*, 1973).

A study by Goldstein *et al.* (1979) claims that each cigarette smoker in the home adds 16 $\mu g/m^3$ of NO_2. However, their additive model is not well described and not without its own inconsistencies. For example, the same study reports a 62 $\mu g/m^3$ reduction in NO_2 for each flueless gas fire and 22 $\mu g/m^3$ reduction for each kerosene heater.

Fig. 1. Labels with interleaved two-of-five barcode format used for sample tube identification.

The purpose of the present study was to measure the contribution of cigarette smoking to the NO_2 level in homes. Unfortunately, a true paired comparison between homes with and without cigarette smoking was difficult. Rather, volunteers were solicited from among our employees for participation, giving almost equal numbers of smokers and nonsmokers.

Sampling, which was performed using the Palmes personal sampler (Palmes *et al.*, 1976; Porter, 1981) for a 7-day average, was simple and inexpensive to perform for a large study. Sample analysis was further automated by using an AutoAnalyzer for determining the NO_2 concentration and a MINC-11 microcomputer for

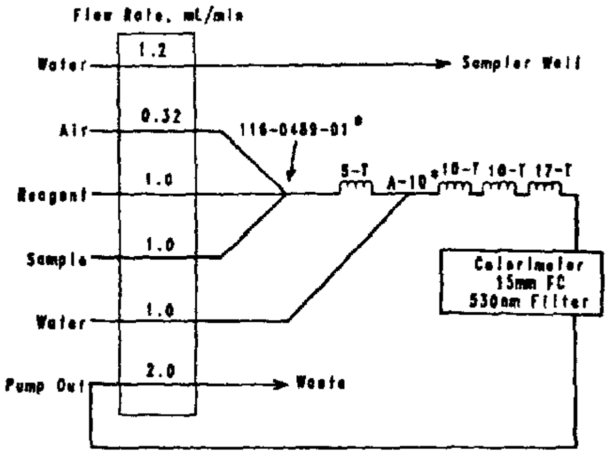


Fig. 2. AutoAnalyzer II configuration for the determination of NO_2. Asterisk denotes Technicon part number.

Table 1. Details of BMDP file. (Units: a = number of days used; b = 1 if present, 0 if absent; c = absolute number of people; d = cigarettes smoked per week; e = $\mu g/m^3$).

Variable	Description	Units
1-2	Name of participant	
3	Baseboard electric heat	a
4	Forced hot air—electric	a

Table 1. (Continued)

Variable	Description	Units
5	Electric heat pump	a
6	Kerosene space heater	a
7	Forced hot air—gas	a
8	Hot water radiator—gas	a
9	Forced hot air—oil	a
10	Hot water radiator—oil	a
11	Open fireplace	a
12	Fireplace with glass doors	a
13	Free-standing wood stove	a
14	Wood stove insert	a
15	Electric oven—summer	a
16	Gas oven—summer	a
17	Microwave oven—summer	a
18	Electric range—summer	a
19	Gas range—summer	a
20	Kitchen vent to outdoors—summer	a
21	Kitchen vent to indoors—summer	a
22	Electric water heater	b
23	Gas water heater	b
24	Oil water heater	b
25	Electric oven—winter	a
26	Gas oven—winter	a
27	Microwave oven—winter	a
28	Electric range—winter	a
29	Gas range—winter	a
30	Kitchen vent to outdoors—winter	a
31	Kitchen vent to indoors—winter	a
32	Central air conditioning	a
33	Window air conditioner	a
34	Attic fan	a
35	Ceiling or window fan	a
36	Auxiliary kitchen fan	a
37	Number of smokers in home—summer	c
38	Number of nonsmokers in home—summer	c
39	Number of cigarettes smoked—summer	d
40	Number of smokers in home—winter	c
41	Number of nonsmokers in home—winter	c
42	Number of cigarettes smoked—winter	d
43	NO_2 living room—summer	e
44	NO_2 bedroom—summer	e
45	NO_2 kitchen—summer	e
46	NO_2 outdoors—summer	e
47	NO_2 living room—winter	e
48	NO_2 bedroom—winter	e
49	NO_2 kitchen—winter	e
50	NO_2 outdoors—winter	e
51	Ratio NO_2 LR/outside—winter	
52	Ratio NO_2 BR/outside—winter	
53	Ratio NO_2 kitchen/outside—winter	
54	Difference NO_2 LR − outside—winter	
55	Difference NO_2 BR − outside—winter	
56	Difference NO_2 kitchen − outside—winter	
57	3-room ratio average—winter	
58	3-room difference average—winter	
59	Ratio NO_2 LR/outside—summer	
60	Ratio NO_2 BR/outside—summer	
61	Ratio NO_2 kitchen/outside—summer	
62	Difference NO_2 LR − outside—summer	
63	Difference NO_2 BR − outside—summer	
64	Difference NO_2 kitchen − outside—summer	
65	3-room ratio average—summer	
66	3-room difference average—summer	

Table 2. Mean NO_2 levels in $\mu g/m^3$ in homes with gas vs. electric kitchen appliances, comparing smokers vs. nonsmokers.

	Kitchen		Living Room		Bedroom	
	Summer	Winter	Summer	Winter	Summer	Winter
Electric (>20 cigarettes)	15.6	21.3	16.5	23.5	14.0	21.3
Gas (>20 cigarettes)	76.3	156.6	66.9	112.2	48.4	96.4
Electric (≤20 cigarettes)	11.8	20.3	12.4	19.6	10.7	17.5
Gas (≤20 cigarettes)	87.0	219.6	47.1	117.4	38.7	97.8

direct data collection and analysis. The majority of the data analysis, however, was performed on a host DEC-SYSTEM 20/60 using statistical routines from BMDP (Biomedical Computer Programs P-Series, Berkeley, CA).

Experimental

A set of 12 sample tubes was prepared for each participant in the manner described in detail by Palmes *et al.* (1981). The 12 tubes were tied together in groups of three for sampling principal areas in the home: living room, bedroom, kitchen, and outdoors. Each individual tube was labeled by sample number, location, and participant name. The sample number was also written as an Interleaved Two-of-Five bar code (Interface Mechanisms, Inc., Lynwood, WA) in order to facilitate acquiring and processing the data (Fig. 1). Additional tubes were prepared and labeled as blanks. These tubes remained closed in the lab during the sam-

Table 3. BMDP3D results comparing NO_2 levels ($\mu g/m^3$) of smokers and nonsmokers without gas kitchen appliances. P is the probability of the observed difference in group means under the hypothesis that smoking has no effect on NO_2 levels.

	Summer		Winter	
	Nonsmoker	Smoker	Nonsmoker	Smoker
Living room				
Mean	12.4	16.5	17.5	21.3
Std. dev.	14.3	10.5	8.4	11.5
Sample size	54	38	49	38
Maximum	86.5	40.8	36.6	49.6
Minimum	−2.5	−0.4	5.7	−1.6
	$P = 0.13$		$P = 0.09$	
Bedroom				
Mean	10.7	14.0	20.3	21.3
Std. dev.	11.7	9.4	9.5	11.1
Sample size	54	38	50	38
Maximum	66.9	42.7	57.1	54.3
Minimum	−2.7	−0.6	5.3	1.4
	$P = 0.16$		$P = 0.64$	
Kitchen				
Mean	11.8	15.6	19.6	23.5
Std. dev.	12.5	10.0	8.1	13.2
Sample size	54	38	49	38
Maximum	72.0	44.7	44.5	65.6
Minimum	−3.4	0.5	5.7	1.4
	$P = 0.12$		$P = 0.12$	
Outside				
Mean	21.3	22.6	52.3	50.0
Std. dev.	13.9	11.6	18.9	20.7
Sample size	54	38	48	35
Maximum	70.5	54.5	99.9	91.3
Minimum	1.1	6.3	18.7	8.9
	$P = 0.64$		$P = 0.62$	

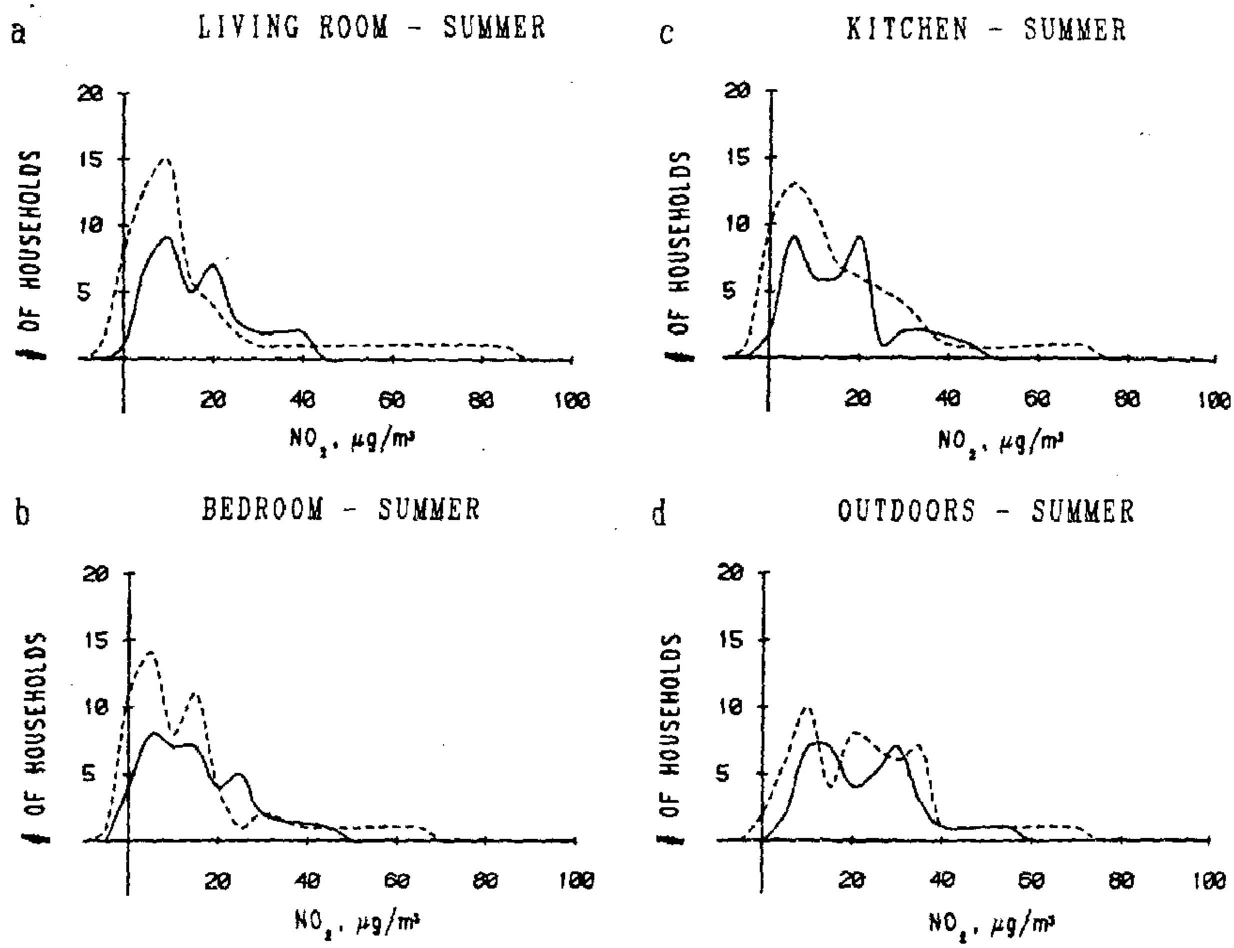


Fig. 3. Curves for the summer study showing the distribution of NO_2 levels (μg/m³) in the (a) living room, (b) bedroom, (c) kitchen, and (d) outdoors for smokers (————) and nonsmokers (------------).

pling period. Participants were also given a log sheet to record the use of specific appliances, heating or cooling plant, and ventilation resources, as well as the number of cigarettes smoked in the home during the 7-day sampling period.

Following the 7 days, sample tubes were mixed with the blank tubes and analyzed in random order, to distribute possible systematic error in the analytical procedure among the samples. The bar codes eased data entry of the then random samples.

A Technicon AutoAnalyzer II system (Technicon Corp., Tarrytown, NY) was designed for the semiautomatic analysis of the NO_2 trapped on the triethanolamine coated grids. The sample tubes were extracted with deionized water and the extract submitted to the AutoAnalyzer. The analyzer was calibrated to measure NO_2 as nitrite colorimetrically via reaction with a sulfanilamide reagent (10 parts) and *N*-(1-naphthyl) ethylenediamine dihydrochloride (1 part) (Fig. 2). The reagent and five sodium nitrite standards were prepared daily. A DEC MINC-11/03 microcomputer (Digital Equipment Corp., Maynard, MA) was used to acquire and process the data. An Intermec Model 9300 bar code reader (Interface Mechanisms, Inc., Lynwood, WA) was connected to an ASCII port of the MINC to provide an alternative to typing the individual sample numbers. The sampling cam on the AutoAnalyzer, selected to give 1 sample/min, provided the time synchronization. The acquisition program, as well as a program that standardized peak heights and converted heights into ng of NO_2 per mL, were written in MINC BASIC. Following completion of the two programs, all sample identification numbers and their NO_2 values were transmitted to a DECSYSTEM 20/60 (Digital Equipment Corp., Maynard, MA) over an RS-232-C communication link.

Individual values were averaged for the same location. Final results were transcribed into a file compati-

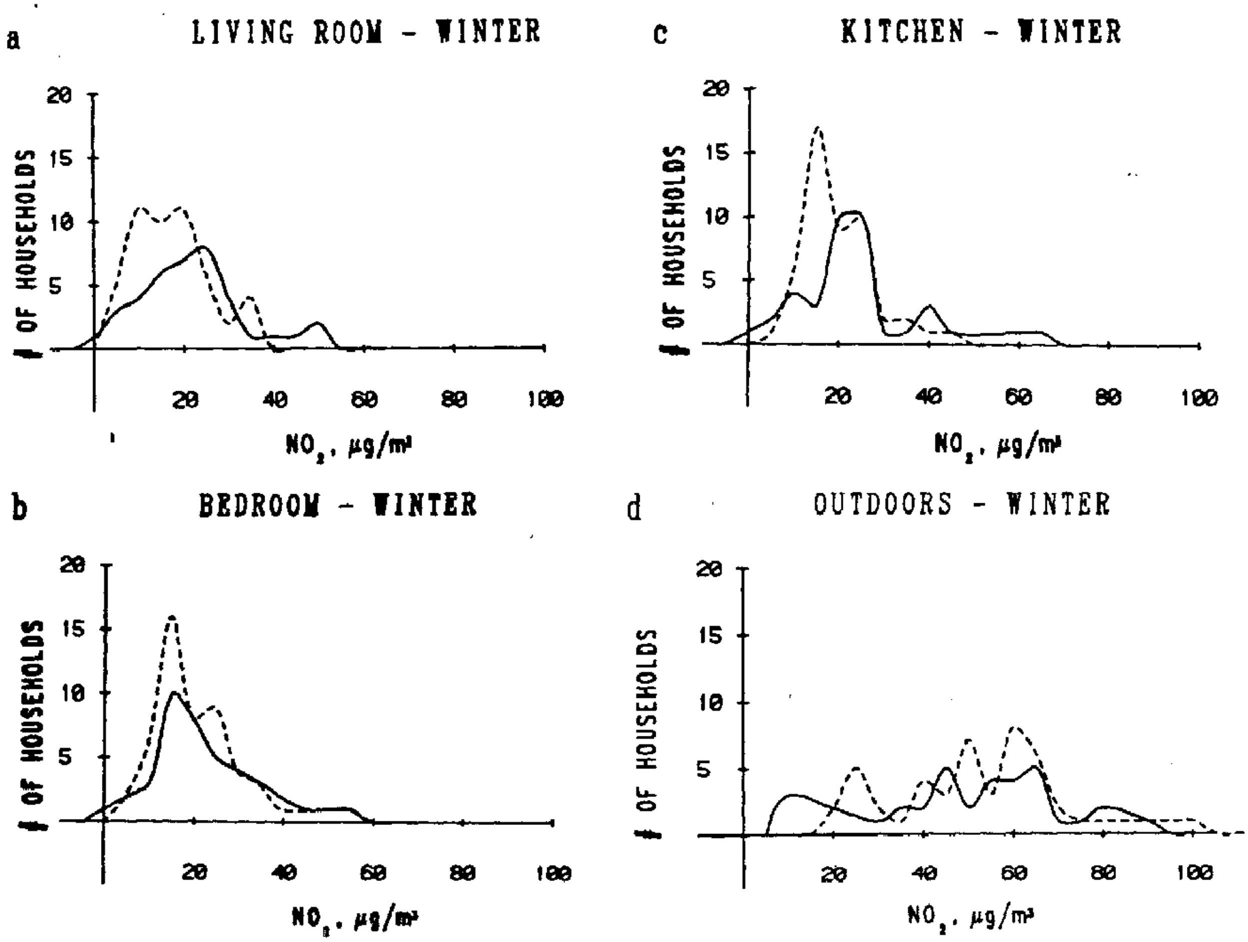


Fig. 4. Curves for the winter study showing the distribution of NO_2 levels (µg/m³) in the (a) living room, (b) bedroom, (c) kitchen, and (d) outdoors for smokers (————) and nonsmokers (- - - - - -).

ble for BMDP input. Table 1 gives a detailed description of the data contained for each case, including the results of the logs provided by the participants and various mathematical transformations of the NO_2 results.

Results and Discussion

There were three objectives in the analysis of the survey: (1) to identify the sources of nitrogen dioxide in the home, (2) to quantify these sources, and (3) to extract trends from the data which may result from cigarette smoking.

Table 4. Geographical distribution of population.

	Smokers		Nonsmokers	
	Summer	Winter	Summer	Winter
Urban	8%	6%	7%	6%
Suburban	84%	80%	72%	77%
Rural	8%	15%	20%	17%

Table 5. Description of population for summer study.

	Smokers	Nonsmokers
Number of participants	38	54
Mean no. of cigarettes smoked	115	2
Average no. nonsmokers in home	2.2	2.7
Average no. smokers in home	1.3	0.3
% use of window AC	29%	28%
% use of central air	58%	57%
% oil water heater	16%	6%
% gas water heater	16%	13%
% electric water heater	68%	81%
% kitchen vent-in	8%	15%
% kitchen vent-out	63%	57%
% electric range	100%	93%
% electric oven	97%	81%
% microwave oven	24%	11%

t-tests

Using BMDP3D, which compares two groups by using *t*-tests, the means of NO_2 levels for smokers versus nonsmokers were obtained. This simple step proved the importance of attempting to make the two groups as equivalent as possible in terms of appliances, ventilation, and outside NO_2 level, leaving cigarettes as the only independent variable. Further comparisons between smokers and nonsmokers will classify a nonsmoker as one who smokes 20 cigarettes or less in the home during the 7-day period.

An illustration of the smoking and nonsmoking participants being unpaired involved the use of gas-fired kitchen appliances. It happened that 8 participants with gas kitchen appliances smoked more than 20 cigarettes, while only 3 smoked 20 or less. It is clear from Table 2, which contrasts smokers versus nonsmokers for cases with gas-fired kitchen appliances, that gas appliances would dominate our comparison between smokers and nonsmokers. Therefore, if these 11 cases are omitted, one can make a more valid measurement between smoking and nonsmoking participants. It should be noted that a probable cause for the high kitchen level in the winter for gas-appliance users was that several of them used range burners as auxiliary heat, resulting in an unvented gas space heater. In these cases, the National Ambient Air Quality Standard (NAAQS) for annual exposure (U.S. EPA, 1971) of 100 $\mu g/m^3$ of NO_2 was exceeded, although the level was substantially below the Threshold Limit Value (TLV) for an 8-h exposure of 10,000 $\mu g/m^3$ (American Conference of Governmental Industrial Hygienists, 1975).

Table 3 summarizes the results of the comparison of smokers versus nonsmokers without gas-fired kitchen appliances. The 3-room average of NO_2 for nonsmokers and smokers is 11.6 and 15.4 $\mu g/m^3$, respectively, for the summer and 19.1 and 22.0 $\mu g/m^3$ for the winter. The outdoor difference between the groups (smokers minus nonsmokers) is 1.3 $\mu g/m^3$ in the summer and -2.3 $\mu g/m^3$ in the winter; these differences are smaller than would be expected by chance.

Figures 3 and 4 demonstrate the complexity of the comparison by showing the NO_2 distribution for the summer and winter, respectively. In all indoor cases, the smoking curve is shifted slightly to the right, while the mean outdoor level appears similar for the two groups. These figures illustrate that the comparison may not be as easy to interpret as Table 3 might suggest. A more complete description of the population involved is included in Tables 4–6.

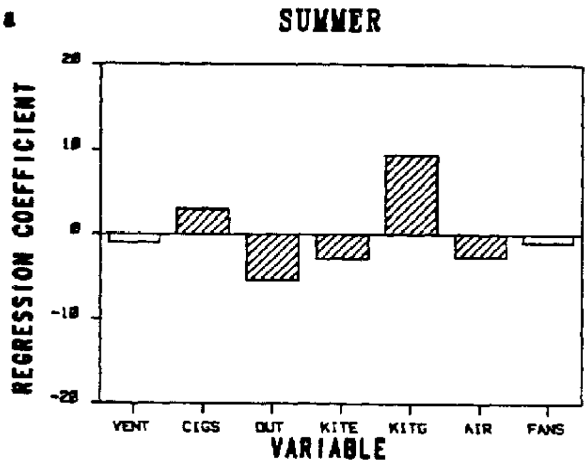
Multiple linear regression analysis

BMDP1R estimates a least-squares regression equation between a dependent variable and one or more independent variables. The dependent variable we selected was variable 66 from Table 1 for the summer and 58 for

Table 6. Description of population for winter study.

	Smokers	Nonsmokers
No. of participants	35	48
Mean no. of cigarettes smoked	102	2
Avg. no. of nonsmokers in home	2.0	2.7
Avg. no. of smokers in home	1.4	0.2
% electric heat	53%	40%
% oil heat	24%	50%
% gas heat	18%	17%
% wood heat	42%	33%
% oil hot water heater	11%	12%
% gas hot water heater	18%	17%
% electric hot water heater	71%	94%
% kitchen vent-in	5%	12%
% kitchen vent-out	61%	54%
% electric range	100%	98%
% electric oven	97%	100%
% microwave oven	24%	17%

a



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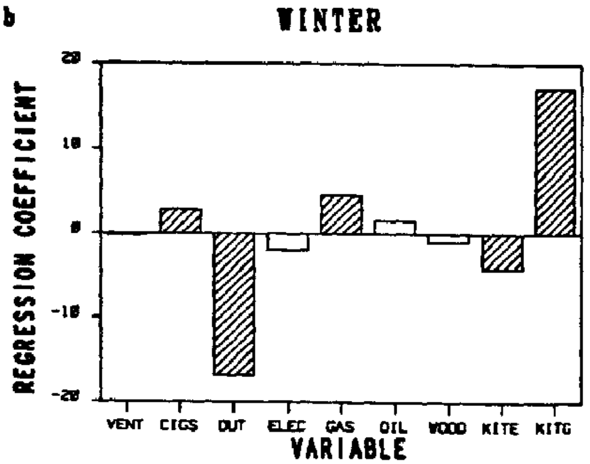

Fig. 5. Linear regression analysis coefficient results (a) for the summer and (b) for the winter. Dependent variables are: VENT, kitchen venting to outdoors; CIGS, number of cigarettes smoked in the house; OUT, the outdoor NO_2 level; KITE, electric kitchen appliances; KITG, gas-fired kitchen appliances; AIR, air conditioning; FANS, attic, ceiling, or window fans; ELEC, electric heat; GAS, gas heat; OIL, oil heat; and WOOD, wood heat. Shaded coefficients designate significance greater than 90%.

the winter, the average of each of the indoor measurements minus the outdoor level. Independent variables for both summer and winter included all electric appliances, all gas-fired kitchen appliances, use of kitchen vent to the outside, outside NO_2 level, and the number of cigarettes smoked. Specific to the summer study, additional independent variables were air conditioning and ventilation. Winter specific independent variables were electric, gas, oil, and wood heat. All independent variables were standardized. The regression results are shown in Fig. 5 and detailed in Table 7. Coefficients with a level of significance less than 0.1 are shaded. The signs of the coefficients demonstrate either the contribution to or removal of NO_2, or the correlation with other variables for the cases in which the variables are not truly independent. The use of a kitchen vent to the outside does seem to lower NO_2 levels, although the regression coefficient has a level of significance greater than 0.1. The larger vent coefficient in the summer versus the winter reflects the greater and, therefore, more effective use of vents in the summer. The outside air obviously provides a significant contribution to both studies; the outside air coefficient is negative because the dependent variable is the indoor NO_2 level minus the outdoor. Since the indoor level is generally lower than the outdoor, the dependent variables are generally negative; the outdoor regression coefficient seems to indicate protection from the outside air which the house offers.

The kitchen appliance regression coefficients illustrate that gas-fired appliances are the predominant term. The electric kitchen coefficient is negative, perhaps not due to its lowering of NO_2, but because of its negative correlation with gas kitchens, i.e., a home would generally have either one or the other. Air conditioners significantly clean the inside air, while fans, merely stirring the inside air or exchanging with the outside, do not have a significant effect on indoor levels. The cigarette coefficient is about 1/3 that of gas-fired kitchens in the summer study and 1/6 of that in the winter. Specific to the winter study, electric, oil, and wood heat did not make a significant contribution, while gas-fired furnaces did.

A correlation plot of predicted (or calculated) versus actual NO_2 levels is shown in Fig. 6, along with the theoretical line.

Factor analysis

BMDP4M is used to accept the entire data base (appliances used, heating/cooling, cigarettes smoked, NO_2 levels) of 28 summer and 35 winter variables and to extract from these, and rotate meaningfully, a lesser number of independent factors. A breakdown of the factors for both studies in terms of the amount of variance explained is shown in Fig. 7. In both cases the

Table 7. BMDP1R results (multiple linear regression) for the summer and winter. All independent variables are standardized. Coefficients are depicted in Fig. 5.

	Variables	Coefficients	t	p(2 tail)
Summer	Intercept	− 4.8		
R = 0.79	Kitchen vent	− 1.1	−1.0	0.32
	Cigarettes	2.8	2.7	0.01
	Outside	− 5.5	−4.8	0.00
	Electric kitchen	− 3.0	−2.0	0.05
	Gas kitchen	9.3	6.4	0.00
	Air conditioning	− 2.7	−2.4	0.02
	Fans	− 1.0	−0.9	0.37
Winter	Intercept	−24.9		
R = 0.87	Kitchen Vent	− 0.2	−0.1	0.89
	Cigarettes	2.8	1.8	0.08
	Outside	−16.9	−9.5	0.00
	Electric Heat	− 1.9	−0.8	0.46
	Gas Heat	4.5	1.7	0.09
	Oil Heat	1.6	0.6	0.54
	Wood Heat	− 1.0	−0.6	0.53
	Electric Kitchen	− 4.1	−1.9	0.06
	Gas Kitchen	17.2	8.1	0.00

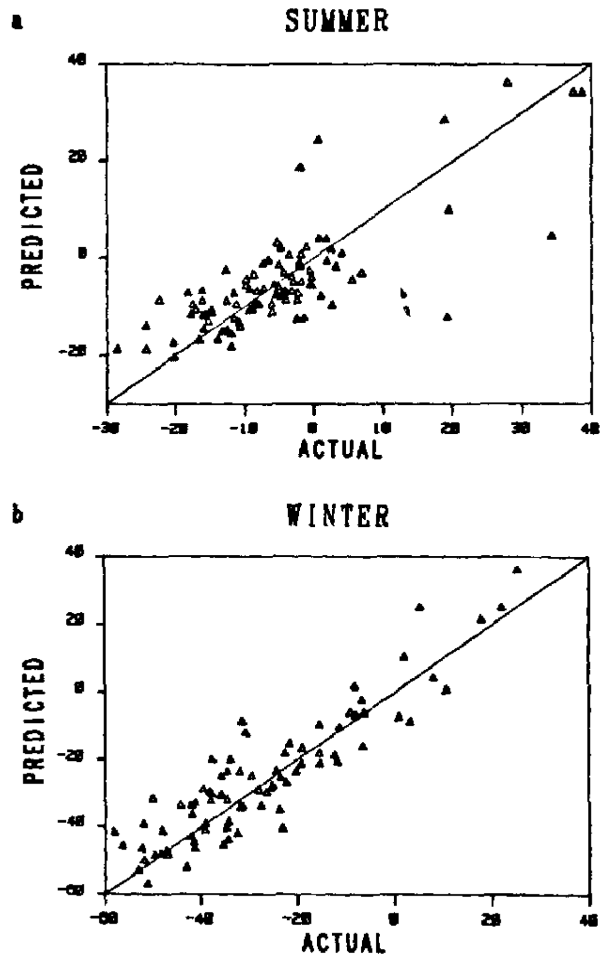

Fig. 6. Linear regression analysis plot of predicted (calculated) vs. actual NO_2 levels (a) for the summer and (b) for the winter. Triangles represent the individual cases. Correlation coefficient (R) equals 0.79 for the summer (a) and 0.87 for the winter (b).

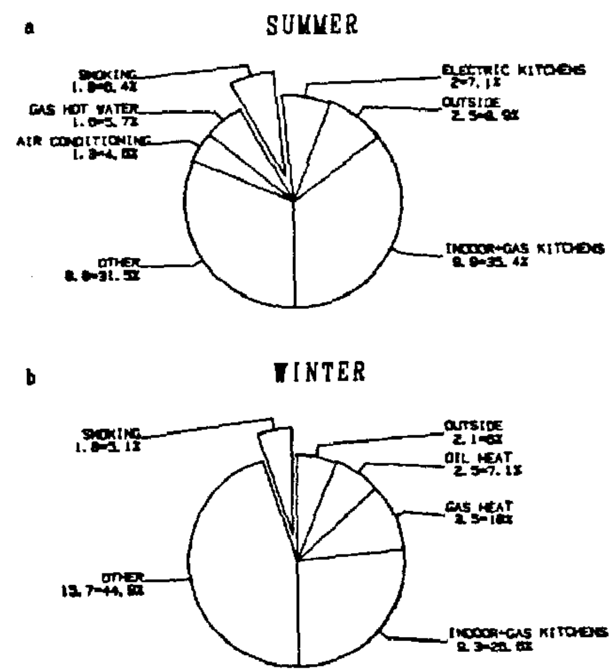

Fig. 7. Pie chart illustrating the percent variance of the entire data base explained by factors from BMDP4M for (a) summer and (b) winter. The smoking factor includes the number of cigarettes smoked and the number of smokers and nonsmokers in the home.

predominant factor was principally loaded, indicating coefficients of near 1.0, while coefficients of other variables are near 0, with all interior NO_2 levels plus gas kitchen appliances. When variables are together in a given factor, it indicates a high degree of interrelationship. The smoking factor, including the number of smokers and nonsmokers, accounts for 5%-6% of the variance of the entire data set (Table 1). This does not indicate a 5%-6% contribution to the indoor NO_2 by cigarettes, but rather, by its exclusion from factor 1, this demonstrates its failure to correlate with indoor levels at all. When we plot scores for factor 1 (inside and gas appliance kitchens) versus factor 2 (outside) for the summer study (Fig. 8a) and label smokers (>20 cigarettes) and nonsmokers, it is difficult to differentiate the groups along the factor 1 axis, although the *S*s appear slightly in the positive direction, which concurs with the *t*-tests results. A similar plot of the winter is shown in Fig. 8b, where differentiation of smokers and nonsmokers is less obvious. An example of the data extraction power of factor analysis is shown in Fig. 9, which plots factor 1 scores (indoor and gas appliance kitchens) against the smoking factor. The plot shows almost 100% differentiation.

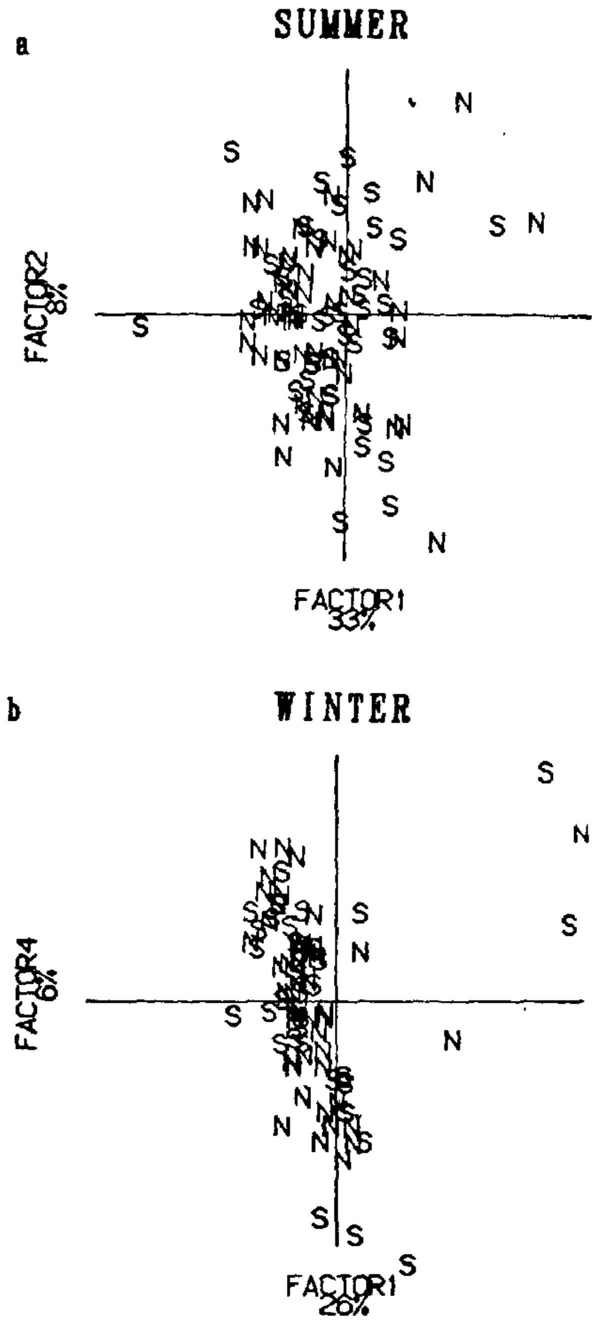

Fig. 8. Factor scores for factors including indoor vs. outdoor NO_2 levels (a) for the summer and (b) for the winter. Cases that smoked 20 or more cigarettes are labeled S, and those that smoked less than 20 are labeled N.

Conclusions

A simple and inexpensive sampling procedure, semi-automated data acquisition, and well-documented statistical methods were effectively combined to show that the increased level of NO_2 due to cigarette smoking is barely measurable over a 7-day period. Furthermore, while the NO_2 increment measured here for participants without gas-fired appliances is 4 and 3 $\mu g/m^3$ in the

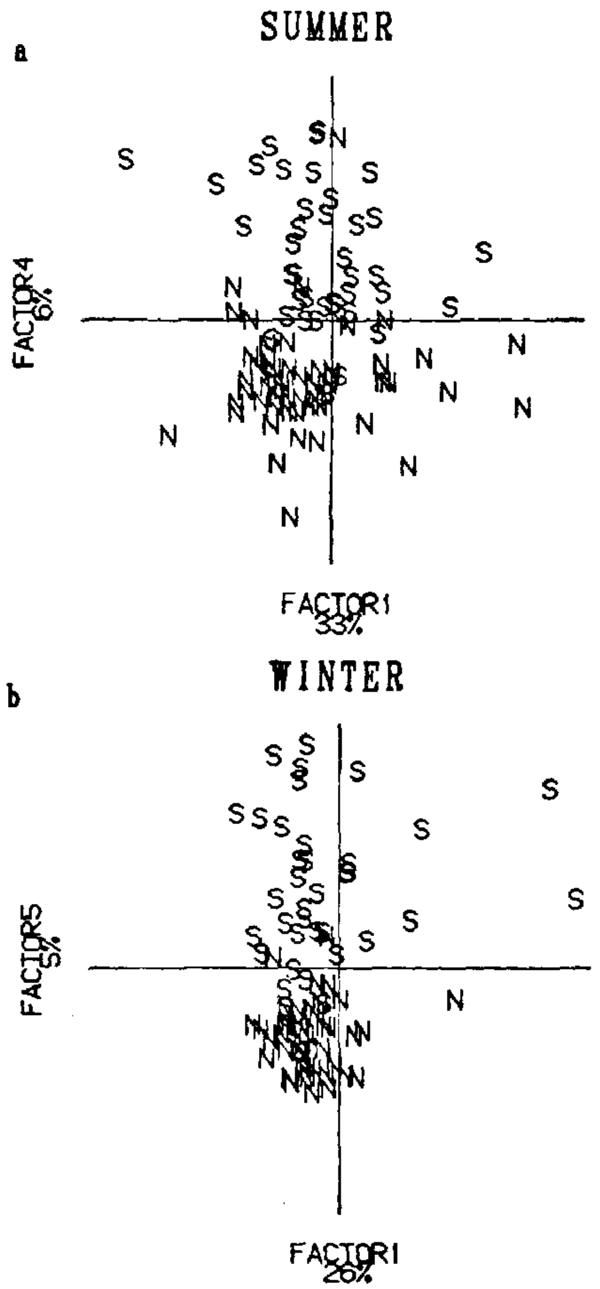

Fig. 9. Factor scores for factor including indoor NO_2 levels vs. the factor including the number of smokers, nonsmokers, and cigarettes smoked in the home during (a) the summer study and (b) the winter study. Cases are labeled as in Fig. 8.

summer and winter, respectively, the absolute levels are well below both the NAAQS of 100 $\mu g/m^3$ for annual exposure and the adjacent outdoor level. In addition, the contribution to the indoor NO_2 level due to gas-fired kitchen appliances completely overpowers that due to the contribution from cigarette smoking.

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